SOURDOUGH ROCK GLACIER, ALASKA: AN ANALOG TO MARTIAN DEBRIS-COVERED GLACIERS

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Introduction: Debris-covered glaciers are found in abundance in the northern and southern mid-latitudes of Mars where they fill craters and valleys and surround the bases of high mesas and massifs [1-4]. They exhibit distinctive flow patterns including flow-parallel lineations and compressional ridges. These morphologies record information about flow patterns [5] which may potentially be used to constrain rheological models [6].

Terrestrial rock glaciers have often been invoked as analogs to Martian debris-covered glaciers [3,7], as they exhibit similar morphology. Rock glaciers range in composition from pure glacier ice under a debris mantle [8] to heterogeneous mixtures of ice and debris [7]. There is no comprehensive understanding of rock glacier dynamics, but some studies suggest that climate as well as flow history may be recorded in transverse ridge morphology [9,10].

The goal of this ongoing study is to investigate the relationships between rock glacier flow, internal structure, and surface morphology by utilizing ground-based and airborne geophysics on Sourdough Rock Glacier in Alaska, as well as assess its viability as a Martian analog.

Study Site: Sourdough Rock Glacier flows down the south slope of Sourdough Peak in the St. Elias Mountains, Alaska. It exhibits numerous transverse compressional ridges in its lower lobe. The middle trunk exhibits highly regular bumps and swales with an average wavelength of 175 m and detrended heights of up to 12 m. In the middle trunk lineations (boulder trains, furrows) diverge around a point roughly 200 m from the eastern edge of the glacier; this may be a bedrock obstacle.

Methods: *Airborne Photogrammetry:* Airborne color photographs was acquired in August 2013, August 2014, May 2015, and August 2015. These are used to create orthophotos and DTMs at sub-meter resolution. Differencing and feature-tracking allows us to extract horizontal and vertical velocities for the surface of Sourdough Rock Glacier.

GPR: Ground-penetrating radar (GPR) data was collected in 6 reflection surveys at 50 and 100 MHz. These include two near the head of the glacier (one of which covers the border between mountain meadow and active rock glacier), two over a bump and swale (one flow-transverse, one flow-parallel), and one which samples the flow-transverse compressional ridges on the lower glacier.

TEM: Transient electromagnetic (TEM) sounding is a method by which the conductivity structure of the subsurface is inferred through electromagnetic induction. A 20 x 20 m wire loop is used to both generate a magnetic field in the subsurface and to record decaying eddy currents induced in the subsurface when the field is shut off. We invert the data to produce a 3-layer subsurface conductivity model.

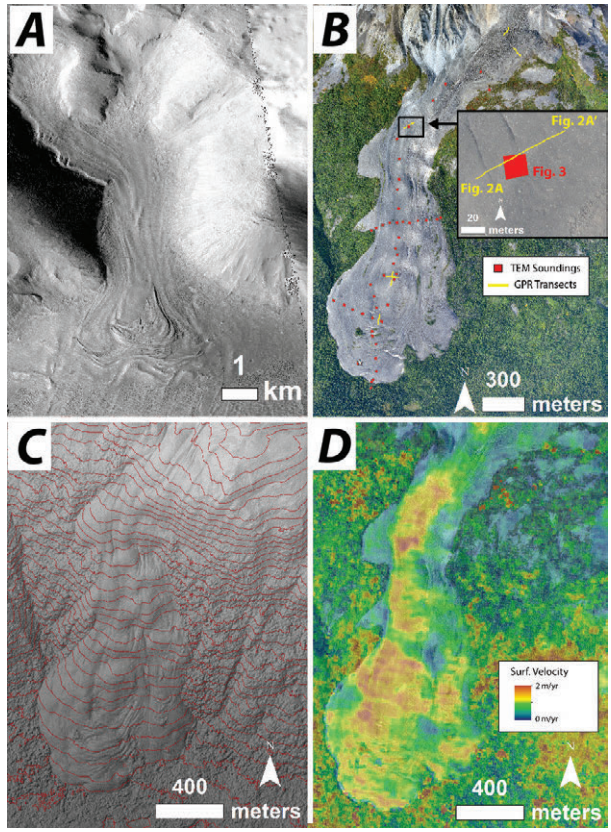

Figure 1: *(A) Martian viscous flow feature. (B) Orthophoto of Sourdough Rock Glacier, Alaska. Acquired TEM soundings and GPR surveys are mapped. (C) Shaded topography produced from airborne photogrammetry. Elevation contours are mapped with 20m interval in red. (D) Horizontal velocities derived from photogrammetry acquired in August 2013 and August 2014.*

Forty-seven TEM soundings were performed, most of which are arranged in a long flow-parallel transect (26 observations) and two flow-transverse transects (6 observations across the low lobe and 11 observations across the middle trunk).

Results: *Airborne Photogrammetry:* Feature tracking produced velocities from August 2013-2014 of up to 2 m/yr. There is a strong correlation between higher surface velocity and steeper slope. There is stagnation at the

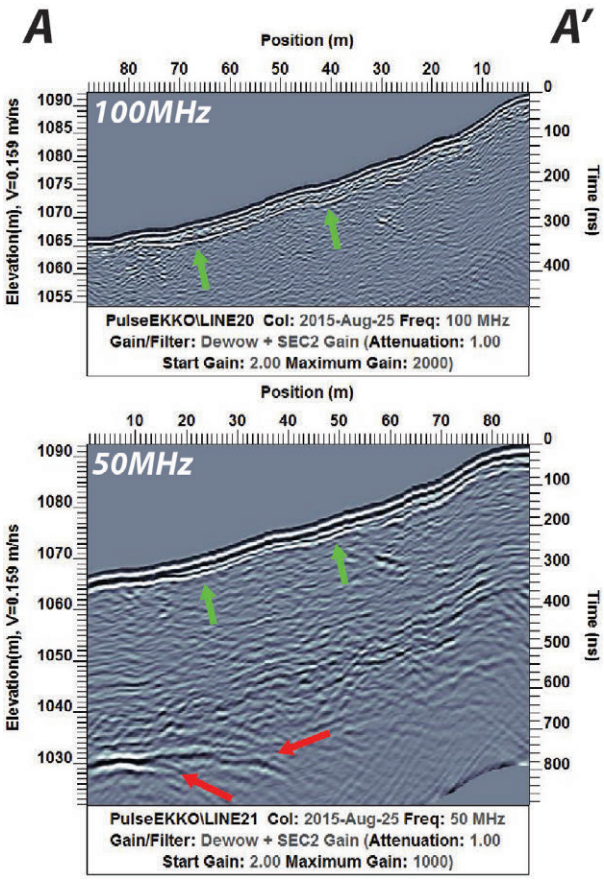

Figure 2: *100 and 50 MHz GPR acquired in the middle trunk of the glacier (Fig. 1B). A shallow reflector observed at a depth of roughly 2.8 m (green arrows) is interpreted to be the interface between surface debris and underlying glacier ice. A strong reflector at a depth of roughly 40 m (red arrow), which is not observed in any of the other GPR surveys, may be base of the glacier.*

point in the middle trunk around which flow lineations bend.

GPR: All GPR reflection surveys revealed a shallow reflector (roughly 50 ns two-way-travel time) that separates an upper layer with high scattering/clutter from a cleaner subsurface. Diffraction hyperbola measured under the shallow reflector yielded a subsurface dielectric constant of 3.6, consistent with relatively pure ice. In one transect a strong reflector was observed at a depth of roughly 40 m (Fig. 2). Little internal structure is observed in association with transverse ridges, in contrast to previous studies [9].

TEM: Most TEM soundings were fit reasonably well with a 3-layer model consisting of a moderately conductive top layer 2-3 m thick over a highly resistive layer 40-50 m thick (i.e. Fig. 3). These are interpreted as the dry surface debris layer and the interior glacier sitting over

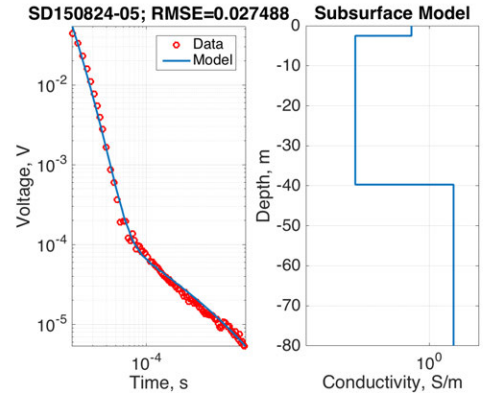

Figure 3: *TEM sounding acquired in the middle trunk of the glacier (Fig. 1B). Best-fit 3-layer model to the measured voltage decay produced layer interface depths of 2.5 m and 40 m, which are coincident with the depths of observed reflectors in GPR acquired for the same location (Fig. 2). The middle layer is highly resistive, consistent with high ice content.*

basement rock. Total glacial thickness as estimated from TEM correlates with the bump and swale topography and thins out directly upstream of the proposed bedrock obstacle in the middle trunk.

Conclusions: We conclude from GPR and TEM data that Sourdough Rock Glacier is 40-50 m thick, consisting of a a core of relatively pure glacier ice preserved under a 2.5-3 m thick debris mantle. It is compositionally as well as morphologically similar to Martian debris-covered glaciers [1,2] and thus a viable analog.

Sourdough Rock Glacier is currently actively flowing, with surface velocities that correlate with surface slope and overall thickness. A bedrock restriction is inferred from bending flowlines, low surface velocities, and local thinning of the deposit.

This work has produced a dataset sufficient to fully constrain rheological models of Sourdough Rock Glacier's flow in future studies. Linking SRG's rheology to its flow morphology will give us insights we may apply to Martian debris-covered glaciers.

References: [1] Holt, J., et al. (2008), Science, 322, 1235-1238. [2] Plaut, J., et al. (2009), GRL, 36(2). [3] Squyres, S. (1978), Icarus, 34(3), 600-613. [4] Hubbard, B., et al. (2014), The Cryosphere, 8(6), 2047-2061 [5] Baker, D., et al. (2010), Icarus, 207(1), 186-209. [6] Parsons, R., et al. (2011), Icarus, 214(1), 246-257. [7] Degenhardt Jr., J., and J. Giardino, JGR, 108(E4), [8] Potter Jr., N., et al. (1998), Geografiska Annaler: Series A, Physical Geography, 80(3-4), 251-265, [9] Florentine, C., et al. (2014), Journal of Glaciology, 60(221), 453-462. [10] Mackay, S., et al. (2014), JGR: Earth Surface, 119(11), 2505-2540.